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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (b)(2).

Docket Number		25181		Type a plus sign (+) inside this box ->	+
INVENTOR(s) / APPLICANT(s)					
LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)		
EFRONI	Sol		Nes Ziona, Israel		
HAREL	David		Beit Zayit, Israel		
COHEN	Irun	R.	Rehovot, Israel		
TITLE OF THE INVENTION (280 characters max)					
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ENCLOSED APPLICATION PARTS (check all that apply)					
<input checked="" type="checkbox"/> Specification	Number of Pages	59	<input checked="" type="checkbox"/> Applicant is entitled to Small Entity Status		
<input checked="" type="checkbox"/> Drawing(s)	Number of Sheets	10	<input checked="" type="checkbox"/> Other (specify) Appendix (12 pgs.)		
METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)					
<input type="checkbox"/> A check or money order is enclosed to cover the filing fees			FILING FEE AMOUNT (\$)		\$ 80.-
<input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number:			50-1407		

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

- ☒ No
☐ Yes, the name of the US Government agency and the Government contract number are: _____

Respectfully submitted,

SIGNATURE

Sol Sheinbein

January 15, 2003
Date

25,457

REGISTRATION NO.
(if appropriate)

TYPED or PRINTED NAME SOL SHEINBEIN

- ☐ Additional inventors are being named on separately numbered sheets attached hereto

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PROVISIONAL APPLICATION

Inventors: SOL EFRONI, DAVID HAREL, and IRUN R. COHEN

Title: REACTIVE ANIMATION

5 FIELD OF THE INVENTION

The present invention relates to a system and method for reactive animation, and in particular to such a system and method in which events are generated and evaluated by an event driven engine for the execution of reactive graphic animation by an animation engine.

10

BACKGROUND OF THE INVENTION

Animation of complex behaviors is very difficult to create, for example for animation of a complex situation, and/or for adding complex behavior to animation. Currently, animation is predetermined, in that the exact behavior of the animation must be known and created in advance. Animation cannot be created by allowing different objects to freely interact, and then creating the animation from such interactions.

One example of a situation which features complex behaviors is for interpreting sets of data in science. The task of collecting data and displaying it in a readily comprehensible format is complex, particularly for dynamic data. For example, scientific papers, often the sources of such dynamic data, may provide a complex dataset for a given phenomena in text, table, and figures that are difficult to

translate into other media. The language used in scientific papers is usually comprehensible only to the specific field of research.

For example a specific scientific topic may be researched in different fields, for example cell migration and cell differentiation, which may include data from histology, electron microscopy, biochemistry, and molecular biology. Each field forms a specific viewpoint and dataset. Therefore, constructing representations of models which are useful for comprehension by scientists in other fields and/or which are useful for phenomena which are not restricted to a particular field, can be quite difficult.

One particularly difficult problem is dynamic modeling of a system, which requires that changes to a system be both modeled and represented. The representation of a dynamic model requires that changes over time be accurately depicted, in a manner which is comprehensible to other scientists.

Theoretically, animation of a model could solve this problem, by allowing dynamic, changing representations of the model to be easily displayed. Unfortunately, animation is currently produced frame by frame, thereby giving the illusion that the objects in the animation perform some interactions among themselves. The objects in this "standard" animation do not sense each other and their behavior is not the outcome of some defined description of stimuli and response. Therefore, this type of representation is not useful for a model, as it is predetermined and does not reflect dynamic changes in the model itself.

Furthermore, animation in general suffers from this limitation, as it limits the possible interactions between objects to those which have been previously determined.

For computer games, for example, such a limitation restricts the ability of a player to interact with the game, and also limits the possible of a realistic representation of a virtual world in the game. This limitation also increases the cost of creating animation, as all visual depictions must be predetermined and manually programmed in the scripting language of the animation tool, rather than allowing such representations to arise naturally as a result of interactions between the objects.

SUMMARY OF THE INVENTION

The present invention is of a system and method for generating reactive animation involved in providing a generic link between tools for the specification and execution of reactive systems and tools for graphic animation. The present invention can optionally be used in a wide range of applications, including computer games, navigation and traffic systems, physiology models, and interactive scientific animation. Reactive animation helps make the programming of such applications more reliable, expeditious and natural. The present invention seeks to operatively link the representation of an event driven system in conjunction with an event driven engine to an animation engine in order to generate reactive animation. Such a combination has not been taught or suggested by the background art, since animation has previously been created according to predetermined methods.

In an optional preferred embodiment of the present invention, the event driven system may be a stateful system and the event driven engine may be a state engine. In an alternative optional preferred embodiment of the present invention, the event driven system may be a sequence of action (scenario based) system and the event

driven engine may be a sequence of action (scenario based) engine. In another optional alternative preferred embodiment of the present invention, the event driven system may be a temporal (time based) system and the event driven engine may be a temporal (time based) engine. The above-mentioned embodiments are by way of example only and are not meant to be limiting.

A stateful system, a system in which the past history of the system's objects impact future behavior of those objects and the system as a whole is well known in the art. Animation as a means of graphical representation of predetermined systems is well known in the art.

In the optional preferred embodiment of a stateful system, the behavior of objects within a given system is modeled within a reactive animation environment. Objects in a reactive animation environment are preferably mapped to physical objects, or optionally conceptual objects.

States may preferably be logically mapped to animation primitives, simple actions carried out by objects which may preferably not be broken down into simpler actions, and which therefore preferably represent the simplest or most basic actions or portions of the animation. The animation is then created by translating each such state into a visual depiction of the action. It should be noted that an action may optionally be descriptive of the object.

For example, within the context of computer games, the animation would require modeling of movement on the behalf of characters and places, as well as visually descriptive aspects of the characters and places, and possibly even the background.

States describe the behavior of each piece of animation separately. Therefore, the animation engine does not need to be cognizant of what is happening in the scene, but only how to arrange all of the requested pieces of animation. The animation engine makes the animation look realistic. Computer games had previously focused
 5 on the appearance of realistic-looking behavior within the game, but were not concerned with actually modeling realistic behavior.

Preferably, in addition to states representing physical changes such as color changes, states may also preferably be mapped to interactions between objects. For example, if an object representing a fist impacts an object representing a piece of
 10 paper, a transitional interactive state of "fist punching paper" which models the animation of a fist punching a piece of paper may be generated which has a very limited life span (e.g. 0.3 seconds) and then dies.

After the transitional interactive state of "fist punching paper" has died, the behavior of the fist and the piece of paper may continue to be modeled by states
 15 representing the fist and states representing the piece of paper respectively. States modeling the behavior of the fist are preferably mapped to animation primitives depicting the fist, which are output onto a display device. States modeling the behavior of the piece of paper are preferably mapped to animation primitives depicting the piece of paper which are output onto a display device.

20 Tools for the execution of reactive systems via state engines are well known in the art. RhapsodyTM from I-Logix, Inc. is an example of a commercially available state engine. Graphical animation tools are also well known in the art. FlashTM from Macromedia is an example of a commercially available animation engine. By way of

example only, and without any intention of being limiting, the present invention is demonstrated with Rhapsody™ as the state engine and Flash™ as the animation engine.

5 BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic block diagram of a preferred exemplary reactive animation system according to the present invention;

10 FIG. 2 is a graphical representation of a UML model depicting a preferred reactive animation system according to the preferred embodiment of the present invention;

FIG. 3 is a schematic depiction of layering within a preferred reactive animation system;

15 FIG. 4 is a schematic block diagram of an exemplary preferred reactive animation method;

FIG. 5 is a schematic block diagram of an exemplary preferred reactive animation method demonstrating the building of a plurality of actor and actor-component movie clips in the animation engine;

20 FIG. 6 is a schematic block diagram of an exemplary preferred reactive animation method demonstrating the building of a simulation/movie /execution/running model in the event driven engine;

FIG. 7 shows part of the actual simulation of a thymus model according to the present invention; and

FIG. 8 shows an exemplary menu according to the present invention.

5 DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a method for providing animation, by determining the behavior of an object according to a plurality of events with an event driven engine, and the visual depiction of that behavior as a plurality of portions of animation by an animation engine. Preferably, an interface translates the information from the event driven engine concerning the event which acted upon the object, into one or more commands for the animation engine. The animation engine then renders one or more portions of animation for display.

In one preferred embodiment of the present invention a method for producing animation of an object includes: modeling a behavior of the object as a plurality of events, determining at least one transition between the plurality of events, creating a visual depiction which at least represents the plurality of events, detecting an event which acts upon the object, and creating the animation according to the event with the corresponding visual depiction.

In an optional preferred embodiment of the present invention, the event driven system may be a stateful system and the event driven engine may be a state engine. In an alternative optional preferred embodiment of the present invention, the event driven system may be a sequence of action (scenario based) system and the event driven engine may be a sequence of action (scenario based) engine. In another

optional alternative preferred embodiment of the present invention, the event driven system may be a temporal (time based) system and the event driven engine may be a temporal (time based) engine. The above-mentioned embodiments are by way of example only and are not meant to be limiting. In the optional preferred embodiment of the present invention, the event driven system may be a stateful system and the event driven engine may be a state engine. Within the optional preferred embodiment of the present invention in which the event driven engine is a state engine, at least one transition may preferably be determined according to at least one rule.

Furthermore within the method described above, the visual depiction may preferably be created to further a visual depiction of at least one transition.

Within a preferred embodiment of the present invention, events cause the event driven engine to potentially react. At the very least, the event driven engine will evaluate whether the event driven engine must take action. Though, any given event may not cause a change of status for an object, the event driven engine must at least evaluate whether or not the status of the event should be changed in response to that event. For example in a stateful system, the state of an object may not change in response to each stimulus.

Events, both external and internal events, represent stimuli to the engine. Internal events occur when there has been a change within the event driven engine. Some other factor affected a change within the event driven engine for whatever reason and that change generates an event.

External events occur when external stimuli act upon the event driven engine within the reactive animation system. For example, user input entered through a user interface may act as a means of generating external events.

Within an exemplary, and optional embodiment of an event driven engine, there may preferably be different sequences of events (scenarios). An event occurs and the event engine evaluates whether a change should occur. If the event does not match to any event which has an effect, the event driven engine may preferably not effect a change. For example, within a scenario based system action follows action and possible scenarios could be, the ball comes to a soccer player, the soccer player hits the ball, and the ball moves somewhere else.

In a stateful system, every state needs to be mapped. For example to represent the behavior of a soccer player in a stateful system all of the states that Soccer player can be in must be represented, for example: the soccer player hitting the ball, the soccer player kicking the ball, the soccer player running with the ball, and the soccer player trying to get the ball.

In another alternative preferred embodiment of the present invention, the event driven engine may be a temporal logic engine and the reactive animation may be modeled by a temporal system, a system in which the status of objects within a system are sampled at discrete moments in time.

In a computer game, there may be more than one sequence, but the sequences are set. However in alternate preferred embodiments of the present invention, there may preferably be multiple sequences or multiple scenarios, multiple states, or multiple objects being sampled with respect to time.

In an exemplary, but preferred embodiment of the present invention a system for producing animation of an object is modeled, in which a behavior of the object is modeled as a plurality of states, including: a state engine for modeling the plurality of states and at least one transition between the plurality of states, an animation engine
 5 for creating a visual representation at least of each of the plurality of states, and an interface for receiving a state of the object from the state engine, and for sending a command to the animation engine for creating the visual depiction according to the state. Within a given stateful system, each state may be entered from multiple other states. For example an "end of game" state may preferably be entered at the end of all
 10 possible paths within a given reactive animation system.

In order to assist in diagramming the states and determining the state of an object, Statecharts may optionally be used. Statecharts is a visual language, invented by D. Harel in 1984 [17, 18] to assist in the development of the avionics system of a new aircraft. Statecharts has since become the subject of research for many groups
 15 [19, 20, 21, 22] as the main formalism used to specify the behavior of complex reactive systems in a variety of industries, and has been adopted as the central medium for describing behavior in the Unified Modeling Language (UML), a world standard for object-oriented specification and design of systems [23].

Behavior in Statecharts is described using states and events that cause
 20 transitions between states. States may contain sub-states thus enabling description at multiple levels, and zooming in and zooming out between levels. States may also be divided into orthogonal states, thus modeling concurrency, allowing the system to reside simultaneously in several different states. Statecharts are rigorous and

mathematically well defined and are therefore amenable to execution by computers. Several tools have been built to support Statecharts- based modeling and execution, and to enable automatic translation from Statecharts to machine code.

Within the system described above, the state engine preferably comprises
5 Rhapsody™ [24] and the animation engine preferably comprises Flash™ as non-limiting examples thereof.

Preferably within the system described above, there is an external input module for sending a command to the interface for interacting with the object.

Additionally within the system described above, the external input module
10 comprises a user interface.

The principles and operation of the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, FIG. 1 is a schematic block diagram of a preferred exemplary reactive animation system according to the present invention.

15 Reactive animation system 100 comprises a state engine 110, an interface 120, and an animation engine 130. The state engine 110 further comprises a state processor 140 and at least one statechart 150 (preferably written in the language, Statecharts). Preferably each object has an associated statechart 150, such that there is a plurality of statecharts 150.

20 The interface 120 further comprises a command parser 160 and a command translator 170. The animation engine 130 further comprises a plurality of animation pieces 180, a rendering engine 190, and an input translator 200. A user interface 210, whereby a user (not shown) may preferably interact with the reactive animation

system 100 may be operatively linked to the animation engine 130. or comprised within the animation engine 130.

In alternate embodiments the user interface 210 may be comprised within the interface 120 or operatively associated with the interface 210.

5 In a preferred embodiment the user interface 210 is preferably implemented as a graphical user interface (GUI). When the user clicks on part of the screen, (for example when working in conjunction with an operating system such as the Windows™ (Microsoft Corp USA) operating system, which can interpret mouse clicks), the animation engine 130 may preferably recognize that an event occurred
10 where a mouse click occurred at these coordinates.

Optionally and preferably the animation engine 130 is implemented as a Flash animation engine, or a similar type of engine with similar capabilities that are known in the art. The Flash engine already has the built in capability to interpret user inputs under certain basic circumstances. Flash understands what these inputs mean with
15 respect to the animation. Flash may then send a command back to the interface 120, informing the interface 120 that a click occurred and sending a query for further instructions.

In an alternative embodiment, the input translator 200 is operatively associated or comprised within the interface 120, in which case, the interface 120 has
20 to determine two types of information. First, the user interface 210 needs to be aware of events caused or driven by the user. For example for a mouse click, the screen coordinates form part of the data for the event. The user interface 210 also has to be

aware of the actions of the animation itself, in order to determine the meaning of the coordinates of the mouse click.

Hence it is preferable for the user interface 210 to be comprised within or operatively associated with animation engines that already have at least a limited
5 ability to interpret events from the user interface 210.

Animation engine 130 preferably has scripting capabilities, such that commands may be passed to animation engine 130 in some type of scripting language. These capabilities are well known in the art, and are provided by many different commercially available animation software programs. Animation engine 130 should
10 preferably be vector based, which is also well known in the art. Vector based animation engines describe objects being displayed on a computer monitor or other type of display as a vector, rather than as a bitmap (which is an actual image). Vector based animation can be described in terms of changes to the display, rather than describing each part of the animation as it changes on the display. Such animation is
15 much simpler to program.

Within the state engine 110, the state processor 140 handles states and state transitions, and is able to cause a transition upon receiving input data. By "causing a transition" it is meant that the state of an object is changed from a first state to a second state. In order to assist in the determination of such transitions, state processor
20 140 preferably comprises software that performs the primary and highly repetitive function of mapping input data (not shown) to various states and commands and inputting the relationships between input data and states into the statechart 150.

Each of a plurality of objects 220 is preferably mapped to one of a plurality of statecharts 150. Each of the plurality of objects 220 represents a plurality of states of an object within an animated environment. For example a subset of the plurality of states for the hand object in a video game reactive animation dataset might comprise a state for a hand at rest, a state for a hand waving, a state for a hand forming a fist, a state for a fist at rest, a state for a fist swinging forward, a state for a fist recoiling backwards, a state for a hand holding a small object, a state for a hand holding a medium object, and a state for a hand holding a large object.

The state engine 110 may preferably not be cognizant of the fact that the state engine 110 is modeling animation information. The state engine 110 is used by the user (not shown) to logically represent the relationships between the plurality of objects 220, and the set of commands (not shown) input by the user that governs the means by which the plurality of objects 220 interact within the animation environment.

The interface 120 is the part of the system that enables the state engine 110 and the animation engine 130 to communicate. Within the interface 120, the command parser 160 interprets the commands generated by the state engine 110 via the construction of commands by the state processor 140 by reading the statechart(s) 150.

The command translator 170 interprets the parsed output of command parser 160 from a form that is intelligible to the state engine 110 into a form that is intelligible to the animation engine 130, preferably producing a plurality of animation pieces 180 and a set of animation instructions (not shown) which the rendering engine

190 utilizes to produce a reactive animation model on a display device (not shown).

By way of example and without being limiting, the display device may comprise any display device as is well known in the art including a television screen and a computer screen.

5 In some preferred embodiments of the present invention, the user (not shown) may not interact with the reactive animation model. In other preferred embodiments of the present invention, the user may interact with the reactive animation model via an optional user interface 210.

In one preferred embodiment of the present invention, user inputs entered via
10 the user interface 210 are translated by the input translator 200 and may preferably directly change the way objects are displayed on the display device by changing the appropriate parts of the plurality of the animations pieces 180. The input translator 200 preferably communicates with animation engine 130, for reasons described in greater detail above, which then sends commands and/or information to command
15 parser 160 about the change(s) that have occurred.

The command translator 170 then interprets these changes into data that can be understood by the state engine 110. The state processor 140 then makes the appropriate change(s) in the current situation of the appropriate statechart(s) 150.

In another alternative preferred embodiment, the user interface 210 may
20 communicate directly with the interface 120 via the input translator 200 (positioned in the interface 120 instead of the animation engine 130). The input translator 200 would then route translated user input data to the command translator 170 in the interface 120. The command translator 120 would then translate and route the data

representing the user initiated changes to both the state engine 110 and the animation engine 130 in a form which both the state engine 110 and the animation engine 130 could respectively utilize. Both the state engine 110 and the animation engine 130 would alter the data as requested by the user via conventional internal means as is well known in the art. Optionally, user interface 210 may be operatively associated with state engine 110.

FIG. 2 is a graphical representation of a portion of a UML model depicting a preferred reactive animation system according to the preferred embodiment of the present invention.

By way of example only, without any intention of being limiting, FIG. 2 illustrates a portion of a Unified Modeling Language (UML) model 300 of a reactive simulation of a car interacting with road traffic. The Unified Modeling Language (UML) model 300 comprises at least one statechart 310 and an object model diagram 320.

The statechart 310 represents a stage tag 330 which demonstrates that the car interacting with road traffic is in state_7. The state mode 340 demonstrates that the car is driving. Within the state mode 340 there are a plurality of state descriptors 350 which further describe the state mode 340.

In the example of a car interacting with road traffic in state tag 330 state_7, the plurality of state descriptors 350 comprise an acceleration module 360 and a direction module 370. The acceleration module further comprises a plurality of acceleration module alternatives 375 comprising accelerating 380, constantspeed 390, and decelerating 400. It should be noted that this diagram shows only a few features of

the state system for clarity only, as additional states may be desirable for this system.

Furthermore, this diagram does not include other classes that may interact with the automobile according to their own states, and as such does not completely represent a traffic model.

5 Acceleration module 360 demonstrates that when the car is driving, the car can either be accelerating, decelerating, or driving at a constant speed. The arrows which point between the alternatives accelerating 380, constantspeed 390, and decelerating 400 demonstrate that from any one of the three alternatives mentioned above, the car can change to any of the other two alternatives.

10 The direction module 370 demonstrates that the car's direction can be left 410, straight 420, or right 430.

 Whenever the scalar quantity of speed is equal to zero within the state mode 340 of driving the car leaves the driving mode 340 of driving and enters the stopped submode 440. When the car is in the stopped submode 440 and the scalar quantity of
15 speed becomes nonzero the car re-enters the state mode 340 of driving.

 The system of the car (not shown) comprises a driver (not shown) who interacts with outside stimuli in the traffic simulation. The object model diagram 320 demonstrates the driver's interaction with outside stimuli. The object model diagram 320 comprises a scan module 450 which models the driver's behavior via the looking
20 module 460. Via the looking module 460 the driver scans the surroundings for factors of interest comprising a plurality of factors 465 preferably represented by a trafficLight 470, a danger flag 480, a carinFront flag 490 representing a car in front of the driver's car, and a policeman 500. Data in the statechart(s) 150 (of FIG. 1) may

preferably be changed in the state engine 110 (of FIG. 1) by the state processor 140 (of FIG. 1) based upon the factor encountered by the driver as encountered by the looking module 460.

After one of the plurality of factors 465 is encountered, and any necessary stage changes are made to the statechart 150, logical control of the object model diagram 340 continues with the looking module 460.

Another part of the model is the infrastructure that enables traffic motion. This infrastructure is a representation of streets and sidewalks to facilitate movement and positioning of all other objects. This infrastructure may be modeled as a two dimensional lattice that holds the positions, sizes and visual features of the reactive objects (cars, people, etc) and stationary objects (roads, buildings, etc).

FIG. 3 is a schematic depiction of logical steps to construct a preferred reactive animation model.

Logical flow 600 demonstrates layering in reactive animation. The Animation Layer 610 communicates with the Reactivity layer 620 via a series of bidirectional messages. The interface 120 (FIG. 1) generates several intermediate layers that enable communication between the Animation layer 610 and the Reactivity layer 620 including, but not limited to, top down data 630 and statistical analyses 640. The interface 120 also preferably comprises customization data for different viewers 650 which enables a given reactive animation system to be displayed on a plurality of different display devices (not shown).

These different layers support statistical analyses of the behavior of different objects and/or sets of objects in the modeled system. For example, each user could

decide to focus on different aspects of the modeled system. Also, the different layers enable different parts of the present invention to be operated by different computers and/or CPUs, further increasing the speed and efficiency of the operation of the present invention.

5 FIG. 4 is a schematic block diagram of an exemplary preferred reactive animation method 700 for a given system.

 In stage 710 a system is specified. For example, and without intention to be limiting, the system may be specified in the form of a UML model (as illustrated in Fig. 2)

10 The system further comprises stage 720 in which a plurality of events which comprise the system are defined. In stage 720, the plurality of events is represented as a plurality of states. In stage 730, the plurality of states is decomposed into a statechart for each object.

 Throughout the system associated with Fig. 4, by way of example only and
15 without any intention of being limiting, the plurality of events is represented as a plurality of states.

 In stage 740, a visual representation of the defined event stages is designed. In Fig. 4, by way of example only and without any intention of being limiting, the representation of events is represented as a representation of states.

20 In an alternative preferred embodiment of the present invention stage 740 and stage 710 may be interchanged in which the plurality of states would be determined from a visual representation.

In stage 750, visual landmarks are identified. Identification of visual landmarks is done on the model of the system. In the model, events (i.e. states), messages and attributes that are important to the visual representation are identified. This stage also involves determining the visual form that an object has in the graphic animation. For example, the visual form may optionally be more abstract or symbolic, or alternatively, more detailed and more realistic.

In the example of FIG. 2, such states could be the car's motion data, different states of a traffic light (colors), different activities of a policeman and different activities of pedestrians. A detailed description of traffic may comprise the opening and closing of a car's door, the motion of a car's steering wheel, the car's light, the lighting of the road, the visibility at different conditions and many additional states and attributes.

In stage 760, visual landmarks are associated with states and / or state transitions.

The visual landmarks marked in stage 750 are linked to different parameters in the model. For example, the car's motion data could be associated with states that represent acceleration data, with attributes that stand for the car's speed, and with the state that indicates the path of motion (left turn, right turn).

In stage 770, formatted messages are preferably determined at least for each state transition. The states and optionally other parameters are now preferably associated with a formal action to execute for one or more state transitions, for example for sending a command to the animation engine. Optionally, the messages are bi-directional, in which the animation engine may also have one or more messages

associated with changes to the animation, for example through input from the user interface.

When one of the parameters is experienced in the model, during run-time, such that an event has occurred, a message is preferably sent to the animation engine.

5 For example, in the traffic model of FIG. 2, a message which indicates that the car will turn left will be chosen when the driver decides to turn left. The message will identify the specific car out of the entire fleet together with an indication to the direction of the turn (in this case "left"). In the model, the car preferably examines the surrounding field of vision, to sample available data on visible information in this
10 field. The driver would then decide to turn left, change lanes or take no action. It should be noted that all of these concepts may optionally and preferably be represented by abstract states, with the ultimate action of the car representing a state transition to a new state.

In stage 780, animation components are designed for visually depicting the
15 states of the system.

The animation engine works with components that are later activated, moved, added and changed according to instructions from the state engine. The design of these components can be made using the animation engine or may be imported from any graphical design tool. The design of these components is best made while keeping
20 in mind their reactivity and possible reactions. When an animated component of a car is designed using the animation engine, an image of a car is made. The animated component of a car may be attached to an animation of a car's move to the left and a car's move to the right. The more detailed description would include the opening and

closing of doors, details of the steering wheel's movements, the dashboard, and different lights and so on.

In stage 790, animation components are assigned to the visual representation of the states using scripting language. Animation engines usually include a scripting language which provides a limited language which comprises the option to apply simple behavior to various components. The scripting language does not make it possible to apply complicated behavior to components, but only to control the motion and appearance of animated objects through non-sophisticated commands. In the example of FIG. 2, a car may have, at a specific moment in time, a fixed speed. To create the illusion of a moving car with the animation engine, a script can be encoded which creates the illusion of the rotation of the wheels. The script may receive data about the car's velocity and manipulate the images that display the car's wheels. This way, the effect of a rotating wheel is demonstrated but the location and angle of the car's wheels do not need to be continuously updated.

In stage 800, functionality is defined which enables the interface to send messages and receive messages from the state engine and the animation engine.

The functionality defined by stage 800 is preferably a module that may be written in the animation engine. This module makes use of the connective capability of the animation engine. In the example of FIG. 2, Flash's XML socket, enables XML files to be sent and received through a TCP/IP connection. Other tools preferably comprise other communications options. Every animation tool that comprises connectivity to other tools may preferably be configured, using a proper addition of modules, to perform stage 800.

In stage 810, functionality is defined which enables the interface to parse messages. Received messages must be parsed to make sense of the information they convey. For example, an XML message of the form `<CAR INDEX = "10" SPEED="90" TURN="L">` should be parsed and interpreted as "The 10th car, going 90, is turning left". The parsing is a convention we, as designers, agree upon as a common language between tools. The message received during animation-time at the Animation engine will be dynamically built according to the dynamics of the running model.

In stage 820, parsed messages sent from the state engine are translated and applied to the animation to control animation components. Parsed messages ultimately control the components of the animation. Whenever a relevant component or animation clip should be added, changed or removed, a proper function is able to bring this behavior into animated realism. Functions are specifically designed to perform different animations. These functions are invoked by parsed messages sent by the reactive modeling tool.

In stage 830, a channel of communication is applied to the state engine, animation engine and interface. There are various alternatives for building a channel of communication between the state engine and the animation engine. According to the particular choice of communication interface (TCP/IP, windows API, etc ...), the channel of communication can be optimized. In the example of FIG. 2, TCP/IP is used. With TCP/IP as a choice of communication channel, the hardware may be easily distributed, since most hardware is built to interact through TCP/IP.

In stage 840, a synchronization of data between the state engine and the animation engine is performed. The beginning of a running simulation may preferably be initialized according to a predefined state setup. For example, the simulation may have initially been populated with a populated fleet of traffic, located
5 in a set of roads. Alternatively the state set up may be populated as the simulation runs. Different cars may be assigned different speeds according to some predefined distribution, or depending upon road conditions. The data structure, optionally as well as other factors define how the state engine and animation engine coordinate with each other for synchronization. Examples of these other factors include but are not
10 limited to, error handling and simulation parameters.

In stage 850, user input is interactively taken into account in determining state data and animation data.

The behavior of many reactive systems, including a complex biological model
15 of T-cell behavior in the thymus, can be modeled with a state engine and animation engine in tandem through an interface which enables the state engine and animation engine to communicate with each other, as described with regard to the illustrative, non-limiting examples below.

20

EXAMPLE 1

IMPLEMENTATION WITH A MODEL

Reference is now made to Figure 5, which is a schematic block diagram of an exemplary preferred reactive animation method demonstrating the building of a plurality of actor and actor-component movie clips in the animation engine.

Reference is also now made to Figure 6, which is a schematic block diagram
 5 of an exemplary preferred reactive animation method demonstrating the construction of a simulation/movie /execution/running model in the event driven engine.

The block diagrams of Fig. 5 and Fig. 6 demonstrate the use of the present invention to construct a film portion with an example of a man walking his dog. The interaction between the event driven engine (a state engine in the present example),
 10 and the animation tool or animation engine, is performed substantially as previously described. More specifically, to behaviorally direct animation from the event driven engine, the user should:

I. Build actor and actor-component movie clips in the animation engine
 (demonstrated in Fig. 5)

15 II. Build the simulation/movie/execution/running-model in the event driven engine
 (demonstrated in Fig. 6)

The method which generates the actor and actor-component movie clips of Fig. 5 is generally designated 900.

20 In stage 905, the actors are built. The man, the dog, the street, the leash, other dogs or other people that may be encountered are graphically designed.

In stage 910, movie clips (for parts of the movie or for the whole movie) are built for any kind of behavior the actors may encounter and respond to. For example, a

movie clip for the dog wagging its tail; for the leash; for the dog's bending and the man's walking may be built.

In stage 915, the animated behavior in response to stimuli is dictated. For example, the command "wag tail" coming from the event driven engine should have
5 an appropriate mechanism in the animation engine that tells the animation to start playing the tail wagging movie clip.

The response to a stimulus should be able to handle features of the stimulus. For example, the command "wag tail" will usually arrive with more data about its features: for example, the speed of wagging.

10 Any scene in the movie is therefore the result of sequential attachment, removal, change of size, change of location, change of angle, change of color, etc. of the different movie clips that comprise the whole movie.

One scene on the movie may be a meeting between two dogs. According to the nature of the meeting (presumably the odors the dogs exchange), the features of the
15 dogs' tails change. If they are two males, for example, the wagging of the tails will be of some specific speed, different from the speed induced by a male-female encounter.

Fig. 6 demonstrates how the simulation/movie/execution/running-model is built in the event driven engine.

The method which demonstrates how the simulation/movie/execution/running-
20 model is built is generally designated 1000.

In stage 1010, the behavior of actors/classes/agents are described and designed. This may be done with tools specifically built for the job (e.g. via RhapsodyTM) or in any other way that is convenient for the designer.

The example has objects such as the man, his dog, other people and their dogs, the infrastructure (the street they walk upon), trees, cars, etc.

The behavior of these objects would usually include the methods that make them move around, the way they sample their environment (sniff, see, feel, hear).

- 5 In stage 1020, the initial conditions are staged. The people and dogs are given a designation of where to be at the start.

In stage 1030, the events which should be sent to the animation engine are specified.

- 10 For example, movements of the man and dog will be reported to the animation engine, but stages of information processing are not reported (unless needed).

In stage 1040, the means through which the messages are sent is specified.

- 15 According to the choice of information the designer wants to deliver to the animation engine, a format for this information is selected. For example, a convenient format for a message about the dog's location would be a reference to the specific dog object, followed by the new coordinates.

In stage 1050, the movie is run.

For example, a simple scene from the movie might be instantiated by the interaction of the animation engine and the state engine. Suppose the scenario is determined as follows:

- 20 "The man is walking his dog using a leash. They meet another dog or detect food."

This scenario provides the overall storyline, or description of the film clip. All possible eventualities need to be defined in the event driven engine. For example, the

man's ability to walk is determined according to his movement along the grid, which is the street. The dog's movement must be similarly constructed.

One example is when the man is using a leash to walk the dog. The physical properties of the leash are combined into the specification: it can't be longer than a
5 predetermined length, it is connected to the man's hand until decided otherwise, it is connected on the other side to the dog. Yet the visual description of the movement is entirely animation engine based. The arch formed when one end of the leash is 1 meter high and the other is 0.5 meters high (the hand of the man and the height of the dog, accordingly) is entirely the work of the animation engine and should include the
10 way arches look in the presence of gravity, etc. The way the arch changes when one of its anchors is moving (the man is walking) is also the work of the animation engine. The way the arch stretches to a full length when one of its anchors abruptly stops moving (the dog stops to sniff) is, again, a movie clip implemented in stage (2) of part I.

15 As another example, consider the 3 dimensional odor space to which the dog may respond. If, for example, an odor source (food) is added somewhere in this space (somewhere in the street), the influence of this source flows in space according to the fluid dynamics of the air in the street. The dynamics are described in the event driven engine. If the dog is capable of responding to scents, at one point or another it might
20 encounter the scent from our odor source (the dog smells the food). If the simulated dog is able to navigate by an odor gradient, the dog moves in the direction of the food. These calculations are performed in the event driven engine.

The animation engine knows nothing of odors, navigation, pulling of the leash or the forces applied by the man on his dog, etc. Yet the animation is capable of showing the dog walking in the direction of the food, because the event driven engine continuously sends messages telling the animation engine the location and direction of the dog. The animation is capable of showing the man's hand stretching when the dog abruptly increases its speed, because the movie clip that shows this stretching of the hand has been prepared and because a message telling the animation to use the clip was sent from the event driven engine, when it detected the need to implement this movie clip. The animation shows two dogs meeting, stopping and passing each other with their tails up, because the clips that include the visual depiction of these interactions have been prepared and can be launched upon demand from the event driven engine.

The event driven engine therefore behaviorally directs the movie, while the animation is the collection of movie clips that are the embodiment of the story.

15

EXAMPLE 2

MODELING A BIOLOGICAL SYSTEM

In this Example, specific analytical data are used to construct an integrated dynamic representation. The integration is preferably performed in two integrated facets: specifying the dataset in a way that makes it amenable to execution on a computer; and representing the objects that are explicitly specified in the first facet, which are cells and molecules. The end result is a moving visual simulation of the biological process – intuitive, visual and interactive. This animation is precisely

executed by the statechart's specification, and not by the user. Further details may also be found in the attached Appendix.

To form the first facet, a detailed description of the relevant objects is prepared. The task of collecting the data and translating it into a well-defined, executable, specification is complex in itself. Scientific papers – the sources of the data – provide the dataset in text, tables and figures that are difficult to translate into other media. The language spoken in biological papers is usually comprehensible only to the specific field of research. The goal is to translate this dataset into a generic and usable medium, which is referred to as specification.

The specifications derived from the actual data are used as a set of instructions guiding the simulation. The cellular and molecular agents comprising the system refer, as it were, to these instructions to know how to respond to stimuli. The stimuli may be interactions with other cells, interactions with other molecules or various internal events such as the passage of time.

Stem cells arrive to the thymus from the bone marrow, and the developing T cells go through a series of interactions in different locations inside the thymus. The processes a single cell goes through take about two weeks [4], during which the cell may proliferate into 10^6 offspring cells [5]. The thymic environment is anatomically divided into lobes and lobules, and the lobules are further divided into the areas of the cortex and the medulla. Since the thymic output of mature T cells is the basis of the immunological repertoire, the physiological function of the thymus is relevant to the study of many diseases, specifically AIDS and autoimmune diseases [6, 7, 8, 9].

5 Different agents constitute the thymus: epithelial cells form a mesh throughout the organ and interact with developing T cells to activate and regulate many of the processes needed for their maturation [10]. Epithelial cells are separated into different subtypes by molecular markers or by anatomical location [11]. Macrophages perform mainly "housekeeping" tasks to clear the thymus of dead cells [12]. Cytokines are the molecules responsible for signaling between the cells. Chemokines are molecules that signal cell movement along gradients [13,14]. Short segments of proteins, called peptides, combine with other molecules (Major Histocompatibility Molecules : MHC) to induce different T-cell selection events (e.g. [15, 16]). Thymocytes (T cells in the thymus) express many different surface molecules that serve for interactions with other cells and molecules. Epithelial cells, macrophages, cytokines, chemokines, peptides, thymocytes and cell markers are all further divided into dozens of subgroups, which are not detailed here.

15 The thymic environment, loaded with these different objects, presents a challenge to many researchers from different fields who have detailed knowledge of some of its parts, but yet wish to comprehend the whole. Consider three scales of analysis: molecules, cells and the whole organ.

20 The molecules most relevant for researchers of the thymus are chemokines, cytokines and receptors on the cell surface. Specialists in cell migration, for example, study how chemokines cause cell migration. They measure chemokine expression levels in different areas of the thymus, on different cells of the thymic stroma and record the responses of thymocytes during different stages of their development. Biophysicists study the interactions between chemokine receptors and their

chemokine ligands at the atomic level. Other researchers study cytokines and their influences on events in thymic development. Cytokines are the main vehicle for signaling between cells and so are important in almost every process. Other molecules allow thymocytes to bind to other cells and to the extra-cellular matrix (ECM).

- 5 Other fields of research look at these molecules in a different way. In microscopy, molecules are used as markers to distinguish between different cells under the microscope. Researchers in signal transduction look at the same molecules to see how they influence a cascade of events inside the cell.

- 10 The questions asked at the cellular level are which cells respond to which stimuli, how many cells of each type are in each thymic area, and how many cell types are in various areas. What are the events that will drive a cell toward one fate and not another? What stages does a cell go through during development? Where is the cell during different stages of development? What are the paths two cells follow when they interact? Which selection events are the most influential? How does mutation
- 15 influence cell survival?

- 20 Researchers looking at the thymus as one whole often see the organ as a "black box". Their questions include: what is the number of cells the thymus produces under specific conditions? How many cells enter the thymus every day/hour/minute? What are the effects of removing the thymus (thymectomy)? Why does the thymus diminish in size with age? What are the influences of diseases on the thymus and what is the influence of the thymus on disease? Are there mathematical formulas that can recapture thymic output behavior?

But the thymus is one whole. Disjointed research parcels the same molecules and cells into separate fields, and produces data that must be joined, if we are to ever understand T cell maturation in the whole organ. Currently, there is no way to integrate this broad spectrum of different types of data into one view that would be as coherent as the biological environment that produced them.

The present invention overcomes this disadvantage by using the data generated by reductionist biology and integrating the data into a specification model using statecharts as previously described. The model is then executed. The results of the execution are used to drive an animated visual image of cells and molecules and their interactions. This type of representation is friendly to human minds, and yet does not sacrifice mathematical precision. Moving cells and molecules are interactive with the thoughts of the user, and the format provides the user with tools to choose specific views and mediate particular types of execution.

Moreover, the representation may optionally be designed to express different theories. Immunology, like other complex and incompletely characterized fields, uses theories to integrate both known and unknown information. Theories are proposed scenarios. The model and simulation can accommodate different theories. Whenever an interaction takes place, the user (or the simulation itself) can choose one theory from a collection of available theories and instantiate that particular theory to its completion in the simulation. The instantiated theory then sends conclusions back to the simulation. The user can choose a particular theory either during run-time or during specification. The outcomes of various theories can be compared and contrasted.

Specifying the Thymus with Statecharts

States and transitions as descriptors of cell behavior

For specification and modeling, as a non-limiting example, the language of Statecharts may optionally be used, as previously described. It is not intuitively obvious that cells and molecules may be naturally described by states and transitions. In fact, there is no consensus on how one should describe cells. However, immunologists, whether they know it or not, do use states to describe cells. A cell is usually described by the collection of markers it expresses on its surface [25]. For example, a T cell is called "double negative" when neither of the CD4 and CD8 molecules is expressed. A human T cell is referred to as a memory cell when it expresses a molecule called CD45RO+ [26] and as a suppressor cell when it co-expresses CD25 and CD4 without being activated [27, 28, 29, 30, 31]. Immunologists call these molecules markers, but the present invention refers to them, during specification, as orthogonal states of the cell. One may object to describing cells according to markers that are not chemically accurate descriptions. However, the notation is the basis of most immunological reports and immunological terminology.

In Statecharts, transitions take the system from one state to another. In cell modeling, transitions are the result of biological processes or the result of user intervention. A biological process may be the result of an interaction between two cells, or between a cell and various molecules.

Dealing with a large dataset

Statecharts provide a controllable way to handle the enormous dataset of cell behavior by providing the ability to specify separation into orthogonal states and by allowing transitions.

5 Examples

Example 1: Modeling thymocyte movement

To demonstrate the conversion of data into specification, the way thymocytes move in the thymus is followed as a non-limiting example. Thymocytes receive signals from different cells in different locations. To be certain that signals are received at the right time is actually to be certain that the right thymocyte is in the right place at the right time. The molecules responsible for directing cells along a gradient path are called chemokines. The role of four chemokines are considered: TECK, SDF, MDC and SLC. Thymocytes search their environment for chemokines and move according to the chemokine gradient. Therefore, (1) the simulating gradient must be correct and (2) the thymocyte must respond only to gradients it can currently interact with.

To determine the right gradient, the scientific literature was surveyed to learn which chemokine is expressed where and at what level. This information is available from different papers, ranging from papers whose subject is one specific chemokine and its expression in the thymus [32], to papers dealing with one specific area in the thymus and the expression of different chemokines in that area (e.g. [33]), to papers reviewing chemokine expression patterns in the thymus as a whole (e.g. [34]). The chemokine dataset was integrated to a four dimensional lattice where each dimension

stands for the concentration of one chemokine. Thymocytes first find out which of the gradients they should probe, calculate the relevant gradient and finally move.

To find which of the gradients a thymocyte may now probe, the model preferably includes cell types as cell states. In the model (as in immunology), cells are distinguished according to surface markers. The model considers which gradients are relevant at some specific stage. In other words, given a cell in a state characterized by the expression of certain markers and given a certain gradient, where will the cell move?

The scientific literature provides seven cell markers as relevant for gradient decisions. Five of them may be either "expressed" or "un-expressed", and two of them have an intermediate level of expression termed "low". The overall number of relevant states is therefore $2^5 \times 3^2 = 288$. At run time, a cell scans through these 288 states, finds the one it is in, and determines which chemokines it may respond to. During specification, each of these 288 states must be examined, to find an equivalent in scientific papers and to provide the biological meaning. During simulation, a decision tree is used to scan through the collection of possible states. Decisions (leafs of the last row) in the tree correspond to cell states. When the scan reaches a conclusion (a leaf), the simulation generates events that tell the cell to which chemokine gradients it may now respond.

20

Example 2: Modeling epithelial cells

Another example of specification is the inclusion of epithelial cells in the model. Epithelial cells in the thymus are stationary, yet their behavior is reactive and

changes continuously in response to various stimuli. The literature divides epithelial cells into many types. Since most of the work has been done using microscopy, the cell types are usually separated by their location and their size. To this microscopic division, temporal behavior was added, which is the expression of different

5 chemokines and cytokines in response to different events. For example, medullary epithelial cells have shorter processes (arms) than other epithelial cells and are usually no longer than 30 micrometer in length. Medullary epithelial cells are considered the main elements in a process called negative selection, and have been therefore extensively measured for levels of expression of MHC class I and class II molecules.

10 Epithelial cells were characterized as having not only a location but also a structure. The structure is the cell processes (arms). As thymocytes and other cells move through the thymus, they interact with the processes of epithelial cells.

Specifying interaction

15 When two cells meet during run time, directions are required to determine how their interaction should proceed. Researchers do not always know all the details of the interaction, and so they use different hypotheses to suggest possible outcomes of the interaction. The hypotheses and their suggested outcomes are referred to as "theories" and outline them as objects with a behavior specified with statecharts.

20 The statecharts of the instance are then executed and, according to different parameters, a conclusion of this interaction is reached. The conclusion may be the death of the T cell, instructions to express one or another marker, instructions to express cytokines, instructions to proliferate, and more. Eventually, the instance

reaches the state marked with "T", which means the instance is terminated and will receive no further references. When another interaction of the same kind takes place, another instance of the same kind will be instantiated. Notice that many instances may co-exist, as the result of many thymocyte-epithelial cell interactions occurring at the same time. According to a particular theory, a single epithelial cell may interact with many different T cells.

Using Statecharts to communicate theories

The diagrammatic nature of Statecharts makes them legible to scientists from different disciplines. To describe a theory with statecharts, a description given in text and non-formal diagrams is transformed into a rigorous, diagrammatic language. The resulting description is easy to communicate.

By regarding theory as a separate component, it is possible to choose to plug in or unplug a theory on demand. A collection of available theories is built, and one is chosen. The choice of which theory should be instantiated may be made before the simulation is started. For example, all interactions between thymocytes and cortical epithelial cells may be determined to follow one theory, while all other interactions follow a different theory. A choice of theory may also be made at run time, and the user can choose to switch between theories. The choice may also be made at run time by the simulation itself, when the right conditions develop. Theory, in the simulation, thus becomes interchangeable during the run. The simulation is only committed to the data, not to its interpretation.

The Front-End: An Interactive Animation

While the simulation runs, a front-end to its activities is generated and presented to the user. The front-end is an interactive visual interface that embodies cells and molecules. The user can actually see what the cells and molecules are doing.

5 The general setup

The representation is a large collection of Flash™ movie clips that are the embodiment of agents and their states as they appear in the simulation running in Rhapsody. While the simulation is generating events and is changing the properties of the interacting agents, the simulation sends information about these changes to
10 generate the Flash movie. The animation is generated on the fly. The animation is neither an end result of the simulation, processed at post-run, nor a preprogrammed movie. It is a living image capturing the look and feel of the physical image of the simulated cells and molecules during run-time.

Figure 7 portrays in part (b) how one thymocyte moves and in part (c) how an
15 interaction with an epithelial cell takes place. Part (a) of the figure gives a snapshot of the running simulation. The figure shows collections of thymocytes around one epithelial cell in the animated user interface. It is important to emphasize that the image of the thymocytes is not a sketch made for the figure but a screen capture of the running simulation.

20 In parts (b) and (c) of the figure, a sketch of two mechanisms that determine the behavior of the cells is shown. In part (b), below the image of the thymocyte parts of the statechart of the thymocyte are shown. Only two sub-statecharts are shown, corresponding to the three markers visible on the cell's surface and not the full

statechart, for the sake of clarity. The thymocyte currently expresses the receptors CD4 and CD8 (the immunological term is DP – Double Positive) and is responsive to the chemokine TECK. Contrary to the two markers for CD4 and CD8, which stand for real surface molecules with that name, the marker for TECK does not signify a

5 molecule, but signifies the ability of the thymocyte to migrate according to a gradient created by that specific chemokine. This notation is used because the experimenters have only limited knowledge of which receptors cause which movements. The available data experimenters provide is of the form “which T cell migrates according to which chemokine” [14, 34, 37, 38, 39, 40]. The sub-statecharts show how receptors

10 are represented as orthogonal states. An expressed receptor will be in the state “high” and an unexpressed receptor will be in the state “low”. On the left statechart, only one state is in “high”. The state represents susceptibility to TECK migration. On the right side, two receptors are in “high” – CD4 and CD8.

To be able to move, the thymocyte represented in the figure (as all other cells)

15 continuously samples its environment. When the thymocyte finds a relevant chemokine gradient – a TECK gradient – it calculates the gradient difference across its surface. Cell movement is directed according to this calculation. In this example, the conclusion is for the thymocyte to move left.

Part (c) of Figure 7 portrays a different mode of operation. The lower part of

20 Figure 7 (a) shows a thymocyte next to part of the arm of an epithelial cell, represented as the two adjacent red diamonds. The thymocyte has just migrated from the right and touched the epithelial cell to its left. When the thymocyte and the epithelial cell meet, the conclusion of this specific interaction is the result of several

checks made during the execution of the statechart, which checks the states the thymocyte, the attributes of the thymocyte and the properties of the epithelial cell, and finally comes up with the conclusion that, in this case, the specific thymocyte should now proliferate. Proliferation will result in the creation of other thymocytes bearing
5 the same markers and having the same attributes as the parent cell. The proliferation updates the Flash movie. When a new thymocyte is created in the movie, an arrow to designate its ancestor appears and then vanishes.

The simulation handles many such events during run-time. Thymocytes continually move around in the simulated thymus, continuously check their
10 environment for stimuli, respond to the stimuli, proliferate, mature, die, change their receptors, secrete cytokines and interact with other cells. All this is displayed at run-time on the user interface and in animated statecharts generated by Rhapsody. Since every agent in the simulation is in effect an instance in Rhapsody, the user may choose to focus on an animated statechart of the agent. Animated statecharts are useful when
15 events and switches in states during simulation are to be studied.

One may, for example, wish to follow the details of the interaction that resulted in migration towards the medulla. Since Rhapsody provides a "step-by-step" mode, we can interrupt the flow of the simulation at any time and continue one step at a time, while paying attention to relevant attributes and following any switches in states the
20 cells go through. Choices made by "theory" instances are followed, resulting in decisions. This course of action may be referred to as "debugging" the simulated biological process. This occurs at two levels. First, one may watch the visual embodiment of the simulation as it develops in the animated representation, to look

for emerging patterns, for dead-end paths, for undefined observables and for mistakes.

To carefully scrutinize parts and time bites, the power of animated statecharts is used to progress step-wise. This allows every agent to be examined as one reactive system and to handle the flood of incoming/outgoing events in a controllable way.

5

Interactivity

Both the visual user interface and the underlying executed animated statecharts allow the user to manipulate the simulation and to retrieve data. This is done in two separate ways.

Interactions via user interface

10

As we explained above, the front-end of the simulation is composed of a collection of movie clips. Each of the movie clips is in fact an interactive menu that allows the user to send data to the running simulation. Since the sent data is in fact an XML object (see "Materials and Methods"), it is not limited in its contents. Available operations are perceived as belonging to one of two kinds: data manipulation or data request.

15

Data manipulation

20

Every object in the animation is also a clickable menu. Figure 8 demonstrates data manipulation and data request upon clicking the animated thymocyte. The menu item "kill T cell" serves as an example of data manipulation. When the user clicks this item, the underlying executing simulation receives notification that it should now tell this specific T cell to perform apoptosis (programmed death). The results of apoptosis are performed in the simulation itself. When the results are processed, the animation

will receive the instruction from the simulation to now delete the thymocyte from current view (and to perform any other representation tasks needed).

The submenu "Change Receptors" opens into four submenus that control the cell's receptors (b). Part (c) of the figure shows the submenu that opens the menu item

5 "Chemokine Receptors". By clicking any element in the checkbox table, the user can change the ability of the cell to migrate to any of the receptors. For example, upon clicking the checkbox in MDC/Yes, the animation sends an event to the simulation. The simulation will then do two things: it will direct the cell that it may now migrate according to MDC and it informs the animation that the thymocyte should now

10 indicate that it is susceptible to MDC (by showing the MDC indicator). The user thus manipulates the simulation exactly in the way data manipulate the simulation. Data manipulation events originating from the user are no different, as far as the simulation is concerned, from events that stem from data specification.

15 Data retrieval

In contrast to data manipulation, data retrieval events do not direct or drive the simulation process. The menu items "Link to Parent", "Developmental Stage" and "Show TCR sequence" of part (a) in Figure 8 are examples of retrieval events. As seen on movie M3 (supporting online material), when the user clicks the menu item

20 "Link to Parent" the animation retrieves a list of the cell's ancestors. With this list, the animation draws arrows indicating the path of the ancestors. The path will start with the selected thymocyte, draw an arrow to the thymocyte that gave it birth and iteratively follow the line of cells up to the primary thymocyte that started the lineage.

The present invention may optionally be used in many different types of implementations and applications, examples of which include, but are not limited to, analysis of any complex and dynamic data; teaching and course design; monitoring the evolution of any system; predicting system behavior in response to intervention; for example, in biological systems, health and disease, pharmaceutical development, system design, system modification, patient monitoring, etc; decentralization of presentation and analysis: the animation may be viewed and studied at sites removed from the site at which the specifications are controlled; organizational planning; strategic and tactical planning in the military; war games, transport, communications, etc; transport and delivery system planning and analysis; any dynamic system that the human mind would understand better by animated visualization; any dynamic system that needs specification, either for design (to help build the system) or for analysis (to know how the system works, e.g. biology) and would benefit from a non-intrusive visualization.

The present invention provides clear advantages, and clearly differs over other attempted solutions that are known in the art. For example, for some computer games, more than one action may be performed at a given point in the game. However, every single path is set even though there may be multiple paths. In other words, computer games only permit a finite number of predetermined paths.

In contrast, in the present invention, there are no preset paths. For example in a stateful system, the path taken by the reactive animation cannot be known in advance. From each state, a transition may be made to any one of a number of different states. With a relatively small number of states, the number of different possibilities becomes huge. When there are enough factors within a stateful system, there may be a combinatorial explosion and the number of paths may effectively become infinite, as the problem of analysis of the different paths becomes NP complete. The present invention overcomes this problem preferably by using a state engine, and decomposing the representation of the system to be animated into a plurality of states, thereby avoiding the necessity to calculate predetermined paths.

References

- [1] M. Meier-Schellersheim, SIMMUNE, a tool for Simulating and Analyzing Immune System Behavior. Doctoral dissertation. DESY (1999).
- 5 [2] D. Harel, Statecharts: A Visual Formalism for Complex Systems. *Sci. Comput. Programming* 8, 231-274 (1987).
- [3] N. Kam, I. R. Cohen, and D. Harel, The Immune System as a Reactive System: Modeling T Cell Activation with Statecharts. To appear in *Bull. Math. Bio.*
- [4] G. Anderson and E. J. Jenkinson, Lymphostromal Interactions In Thymic
10 Development And Function. *Nature Reviews Immunology* 1, 31-40 (2001).
- [5] M. Egerton, R. Scollay, and K. Shortman, The Kinetics of Mature T Cell Development in the Thymus. 87, 2579 (1990).
- [6] D. C. Douek, J. M. Brenchley, M. R. Betts, D. R. Ambrozak, B. J. Hill, Y. Okamoto, J. P. Casazza, J. Kuruppu, K. Kunstman, S. Wolinsky, Z. Grossman,
15 M. Dybul, A. Oxenius, D. A. Price, M. Connors, and R. A. Koup, HIV preferentially infects HIV-specific CD4⁺ T cells. *Nature* 417, 95-8 (2002).
- [7] D. C. Douek, M. R. Betts, B. J. Hill, S. J. Little, R. Lempicki, J. A. Metcalf, J. Casazza, C. Yoder, J. W. Adelsberger, R. A. Stevens, M. W. Baseler, P. Keiser, D. D. Richman, R. T. Davey, and R. A. Koup, Evidence for increased T cell
20 turnover and decreased thymic output in HIV infection. *J Immunol* 167, 6663-8 (2001).

- [8] I. R. Cohen, *Tending Adam's Garden: Evolving the Cognitive Immune Self*, Academic Press, London (2000).
- [9] J. Holoshitz, A. Matitau, and I. R. Cohen, Role of the thymus in induction and transfer of vaccination against adjuvant arthritis with a T lymphocyte line in rats. *J Clin Invest* 75, 472-7 (1985).
- [10] R. N. Germain, T-cell development and the CD4-CD8 lineage decision. *Nat Rev Immunol* 2, 309-22 (2002).
- [11] B. Von Gaudecker, M. D. Kendall, and M. A. Ritter, Immuno-electron microscopy of the thymic epithelial microenvironment. *Microsc Res Tech* 38, 237-49 (1997).
- [12] N. Platt, H. Suzuki, Y. Kurihara, T. Kodama, and S. Gordon, Role for the class A macrophage scavenger receptor in the phagocytosis of apoptotic thymocytes in vitro. *Proc Natl Acad Sci U S A* 93, 12456-60 (1996).
- [13] A. Zlotnik and O. Yoshie, Chemokines: a new classification system and their role in immunity. *Immunity* 12, 121-7 (2000).
- [14] A. M. Norment and M. J. Bevan, Role of chemokines in thymocyte development. *Semin Immunol* 12, 445-55 (2000).
- [15] K. Yasutomo, B. Lucas, and R. N. Germain, TCR signaling for initiation and completion of thymocyte positive selection has distinct requirements for ligand quality and presenting cell type. *J Immunol* 165, 3015-22 (2000).
- [16] N. K. Nanda and E. E. Sercarz, The positively selected T cell repertoire: is it exclusively restricted to the selecting MHC? *Int Immunol* 7, 353-8 (1995).

- [17]D. Harel, Statecharts: A Visual Formalism for Complex Systems. *Sci. Comput. Programming* 8, 231-274 (1987).
- [18]D. Harel and M. Politi, *Modeling reactive systems with statecharts : the statemate approach*, McGraw-Hill, New York (1998).
- 5 [19]I. Khriiss, M. Elkoutby, and R. K. Keller, Automating the Synthesis of UML Statecharts Diagrams from Multiple Collaboration Diagrams. *Lecture Notes in Computer Science* 1618, 132-147 (1999).
- [20]S. A. Seshia, R. K. Shyamasundar, A. K. Bhattacharjee, and S. D. Dhodapkar, A Translation of Statecharts to Esterel. *Lecture Notes in Computer Science* 10 1709, 983-1007 (1999).
- [21]A. Maggiolo Schettini, A. Peron, and S. Tini, CONCUR '96: Concurrency Theory (Pisa). *Lecture Notes in Computer Science* 1119, 687-902 (1996).
- [22]K. Bogdanov, M. Holcombe, and H. Singh, Automated Test Set Generation for Statecharts. *Lecture Notes in Computer Science* 1641, 107-121 (1999).
- 15 [23]C. Kobryn, UML 2001: A Standarization Odyssey. *Communications of the ACM* 42, 29-37 (1999).
- [24]D. Harel and E. Gery, Executable Object Modeling with Statecharts. *IEEE Computer* 30, 31-42 (1997).
- [25]D. B. Sant'Angelo, B. Lucas, P. G. Waterbury, B. Cohen, T. Brabb, J. 20 Goverman, R. N. Germain, and C. A. Janeway Jr, A molecular map of T cell development. *Immunity* 9, 179-86 (1998).

- [26]R. W. Dutton, L. M. Bradley, and S. L. Swain, T cell memory. *Annu Rev Immunol* 16, 201-23 (1998).
- [27]E. M. Shevach, CD4+ CD25+ suppressor T cells: more questions than answers. *Nat Rev Immunol* 2, 389-400 (2002).
- 5 [28]F. Mor, B. Reizis, I. R. Cohen, and L. Steinman, IL-2 and TNF receptors as targets of regulatory T-T interactions: isolation and characterization of cytokine receptor-reactive T cell lines in the Lewis rat. *J Immunol* 157, 4855-61 (1996).
- [29]I. R. Cohen and H. Wekerle, Regulation of T-lymphocyte autosensitization. *Transplant Proc* 5, 83-5 (1973).
- 10 [30]D. Elias, Y. Tikochinski, G. Frankel, and I. R. Cohen, Regulation of NOD mouse autoimmune diabetes by T cells that recognize a TCR CDR3 peptide. *Int Immunol* 11, 957-66 (1999).
- [31]A. Coutinho, S. Hori, T. Carvalho, I. Caramalho, and J. Demengeot, Regulatory T cells: the physiology of autoreactivity in dominant tolerance and
15 "quality control" of immune responses. *Immunol Rev* 182, 89-98 (2001).
- [32]M. Zaitseva, T. Kawamura, R. Loomis, H. Goldstein, A. Blauvelt, and H. Golding, Stromal-derived factor 1 expression in the human thymus. *J Immunol* 168, 2609-17 (2002).
- [33]D. Chantry, P. Romagnani, C. J. Raport, C. L. Wood, A. Epp, S. Romagnani,
20 and P. W. Gray, Macrophage-derived chemokine is localized to thymic medullary epithelial cells and is a chemoattractant for CD3(+), CD4(+), CD8(low) thymocytes. *Blood* 94, 1890-8 (1999).

- [34] W. Savino, D. A. Mendes-da-Cruz, J. S. Silva, M. Dardenne, and V. Cotta-de-Almeida, Intrathymic T-cell migration: a combinatorial interplay of extracellular matrix and chemokines? *Trends Immunol* 23, 305-13 (2002).
- [35] L. Carmel, D. Harel, and Y. Koren, Drawing Directed Graphs Using One-Dimensional Optimization. To Appear in Graph Drawing 2002. (2002).
- [36] C. Janeway et. al., *Immunobiology : the immune system in health and disease*, Garland Pub., New York (2001).
- [37] F. Annunziato, P. Romagnani, L. Cosmi, E. Lazzeri, and S. Romagnani, Chemokines and lymphopoiesis in human thymus. *Trends Immunol* 22, 277-81 (2001).
- [38] J. R. Taylor Jr, K. C. Kimbrell, R. Scoggins, M. Delaney, L. Wu, and D. Camerini, Expression and function of chemokine receptors on human thymocytes: implications for infection by human immunodeficiency virus type 1. *J Virol* 75, 8752-60 (2001).
- [39] C. H. Kim, L. M. Pelus, J. R. White, and H. E. Broxmeyer, Differential chemotactic behavior of developing T cells in response to thymic chemokines. *Blood* 91, 4434-43 (1998).
- [40] J. J. Campbell, J. Pan, and E. C. Butcher, Cutting edge: developmental switches in chemokine responses during T cell maturation. *J Immunol* 163, 2353-7 (1999).
- [41] M. R. Tourigny, S. Mazel, D. B. Burtrum, and H. T. Petrie, T cell receptor (TCR)-beta gene recombination: dissociation from cell cycle regulation and

- developmental progression during T cell ontogeny. *J Exp Med* 185, 1549-56 (1997).
- [42]E. F. Lind, S. E. Prockop, H. E. Porritt, and H. T. Petrie, Mapping precursor movement through the postnatal thymus reveals specific microenvironments supporting defined stages of early lymphoid development. *J Exp Med* 194, 127-34 (2001).
- [43]C. Penit, B. Lucas, and F. Vasseur, Cell expansion and growth arrest phases during the transition from precursor (CD4-8-) to immature (CD4+8+) thymocytes in normal and genetically modified mice. *J Immunol* 154, 5103-13 (1995).
- [44]C. C. Bleul and T. Boehm, Chemokines define distinct microenvironments in the developing thymus. *Eur J Immunol* 30, 3371-9 (2000).
- [45]B. S. Youn, C. H. Kim, F. O. Smith, and H. E. Broxmeyer, TECK, an efficacious chemoattractant for human thymocytes, uses GPR-9- 6/CCR9 as a specific receptor. *Blood* 94, 2533-6 (1999).
- [46]C. Hernandez-Lopez, A. Varas, R. Sacedon, E. Jimenez, J. J. Munoz, A. G. Zapata, and A. Vicente, Stromal cell-derived factor 1/CXCR4 signaling is critical for early human T-cell development. *Blood* 99, 546-54 (2002).
- [47]M. A. Ritter and Crispe I. N., *The Thymus*, Oxford University Press, New York (1992).
- [48]M. Tomita, Whole-cell simulation: a grand challenge of the 21st century. *Trends Biotechnol* 19, 205-10 (2001).

[49] Bartol T. M. and Stiles J. R., MCell. <http://www.mcell.cnl.salk.edu/> . 2002.

[50] I. R. Cohen, *Talmudic Texts for Visiting Scientists: On the Ideology and Hermeneutics of Science*. In preparation.

WHAT IS CLAIMED IS:

1. A method for producing animation of an object comprising:
modeling a behavior of the object as a plurality of events;
creating a visual depiction at least of said plurality of events;
detecting an event associated with the object; and
creating the animation according to said event with said visual depiction.
2. A method according to claim 1, wherein said plurality of events comprises a plurality of temporal samples or a plurality of scenarios.
3. A method according to claim 1, wherein said plurality of events comprises a plurality of states.
4. The method according to claim 3, further comprising:
determining at least one transition between said plurality of states.
5. The method of claim 4, wherein said at least one transition is determined according to at least one rule.
6. The method of any of claims 3-5, wherein said creating said visual depiction further comprises creating a visual depiction of said at least one transition.

7. The method of any of claims 3-6, wherein said state represents an interaction between a plurality of objects.
8. The method of any of claims 3-7, further comprising:
interacting between a plurality of objects; and
altering a state of at least one object according to said interacting.
9. The method of any of claims 3-8, further comprising:
receiving an external input; and
altering a state of at least one object according to said external input.
10. The method of claim 9, wherein said external input is provided through a user interface.
11. The method of claim 10, wherein said user interface is for interacting with a computer game.
12. The method of any of claims 3-11, wherein said detecting said state is performed by a state engine, and wherein said creating the animation is performed by an animation engine, the method further comprising:
receiving a command from said state engine;
parsing said command to determining said state of said object; and

translating said command to a format for said animation engine for creating the animation.

13. A system for producing reactive animation of an object, wherein a behavior of the object is modeled as a plurality of events, comprising:

- (a) an event driven engine for modeling the plurality of states and at least one transition between the plurality of events;
- (b) an animation engine for creating a visual depiction at least of each of the plurality of events; and
- (c) an interface for receiving an event associated with the object from the event driven engine, and for sending a command to said animation engine for creating said visual depiction according to said event.

14. The system according to claim 13, wherein:

Said event driven engine comprises a temporal logic engine or a scenario based engine; and

Said plurality of events comprises a plurality of time samples or a plurality of scenarios.

15. The system according to claim 13, wherein:

said event driven engine comprises a state engine; and

said plurality of events comprises a plurality of states.

16. The system according to claim 15, further comprising:

a plurality of statecharts; and

a state processor.

17. The system according to any of claims 13-16, wherein the animation engine comprises:

a plurality of animation pieces;

a rendering engine; and

an input translator.

18. The system of claim 14, wherein said state engine comprises Rhapsody™ and said animation engine comprises Flash™.

19. The system according to any of claims 13-18, further comprising:

(d) an external input module for sending a command to said interface for interacting with the object.

20. The system of claim 19, wherein said external input module comprises a user interface.

21. The system of claim 20, wherein the user interface operates in response to mouse clicks.

22. The system of claim 20, wherein the user interface is comprised within the animation engine.
23. The system of claim 20 wherein the user interface is operatively associated with the animation engine.
24. The system of claim 20 wherein the user interface is comprised within the interface.
25. The system of claim 20 wherein the user interface is operatively associated with the interface.
26. A method for analyzing a biological system, the biological system featuring a plurality of biological components, the method comprising:
 - providing data related to a plurality of activities of the plurality of biological components of the biological system;
 - analyzing the data to form at least one specification;
 - constructing a plurality of states and at least one transition for at least a portion of the plurality of biological components according to said at least one specification;
 - and
 - creating a visual depiction of said at least a portion of the plurality of biological components in each of said plurality of states.

27. The method of claim 26, further comprising:

detecting a state of at least one biological component; and
creating animation according to said state with said visual depiction.

28. The method of claim 27, wherein the biological system comprises a thymus.

29. A method for analyzing a biological system, the biological system featuring a plurality of biological components, the method comprising:

providing data related to a plurality of activities of the plurality of biological components of the biological system;

analyzing the data to form at least one specification;

decomposing said at least one specification into a plurality of events for at least a portion of the plurality of biological components according to said at least one specification; and

creating reactive animation of said at least a portion of the plurality of biological components, said reactive animation being at least partially determined according to said plurality of events.

ABSTRACT

A system and method for generating reactive animation involved in providing a generic link between tools for the specification and execution of reactive systems and tools for graphic animation. The present invention can optionally be used in a wide range of applications, including computer games, navigation and traffic systems, physiology models, and interactive scientific animation. Reactive animation helps make the programming of such applications more reliable, expeditious and natural.

Figure 1

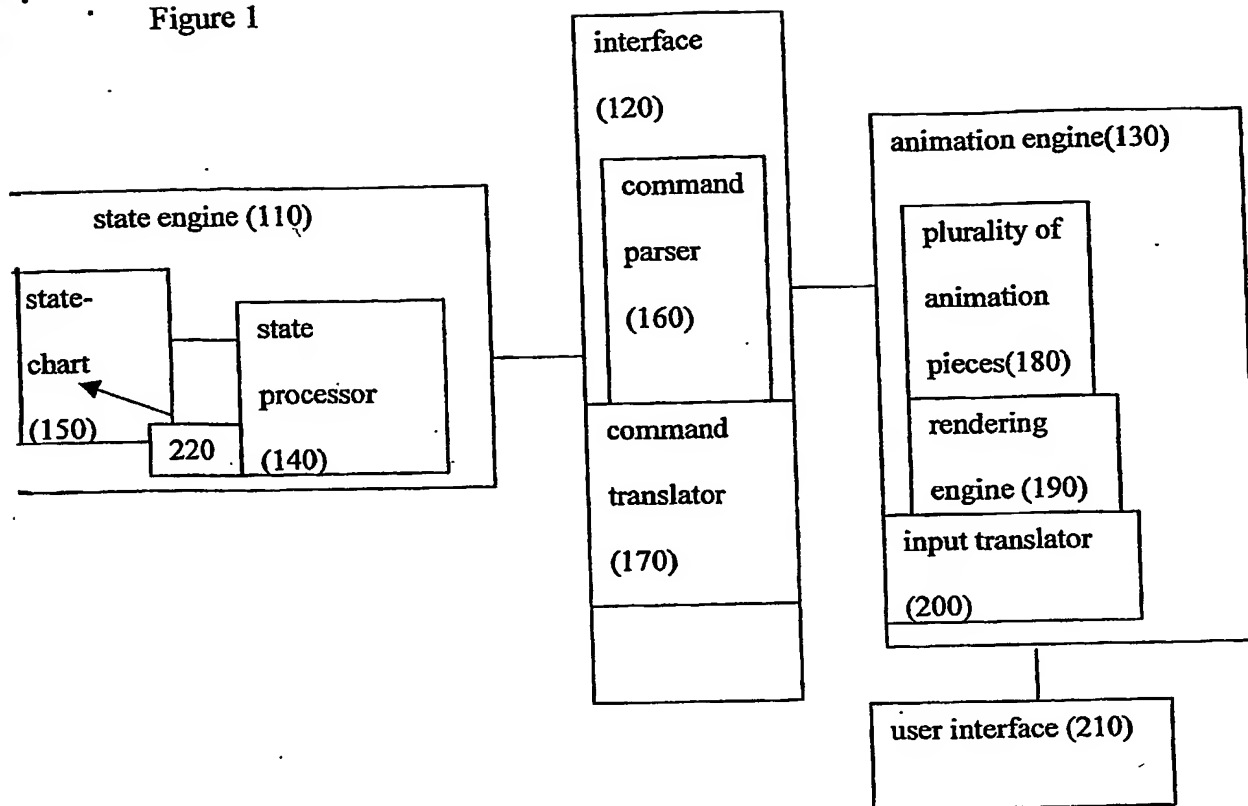
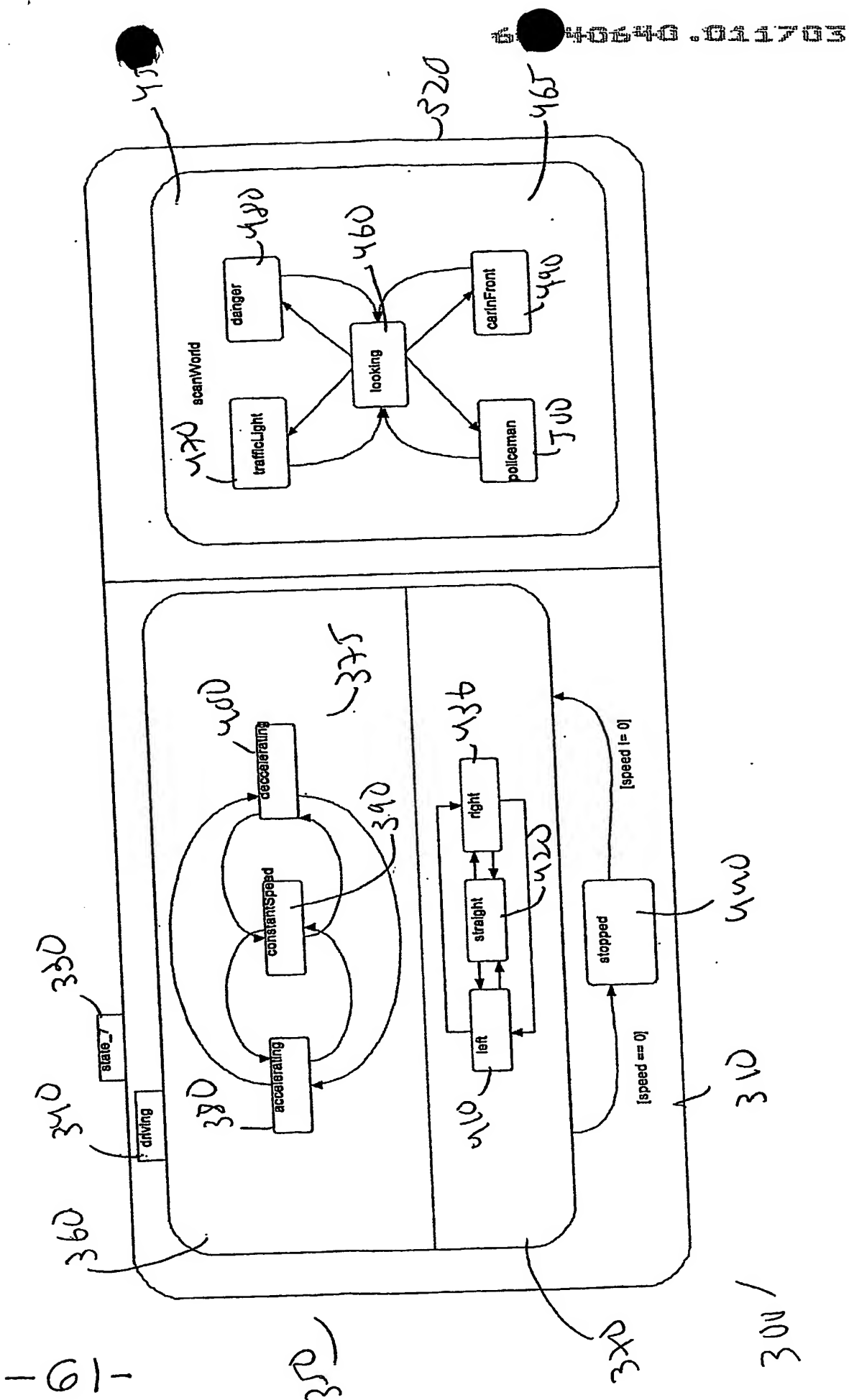


Figure 2



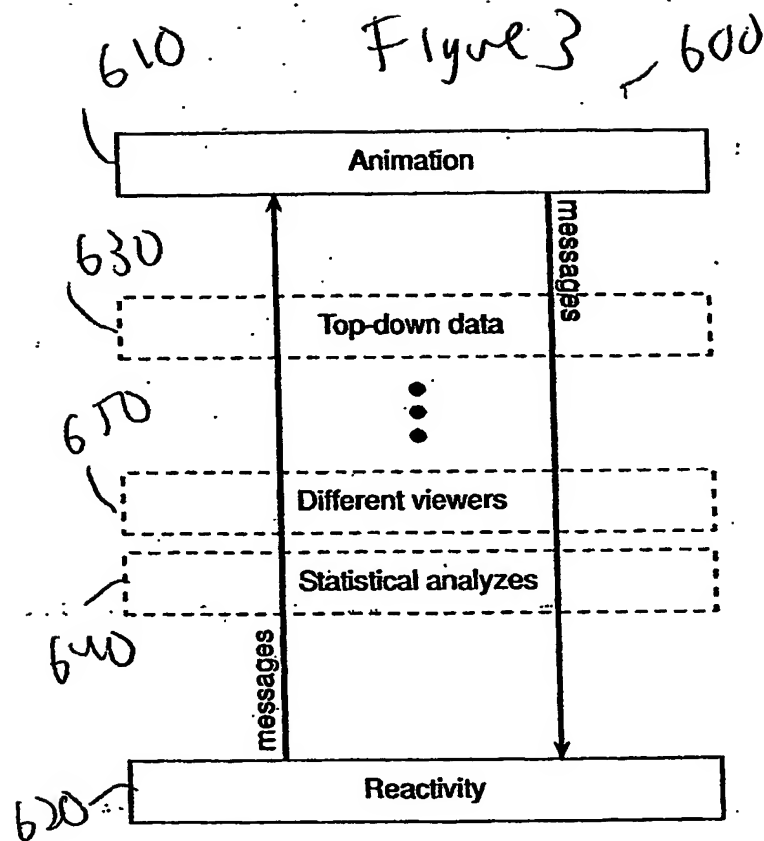
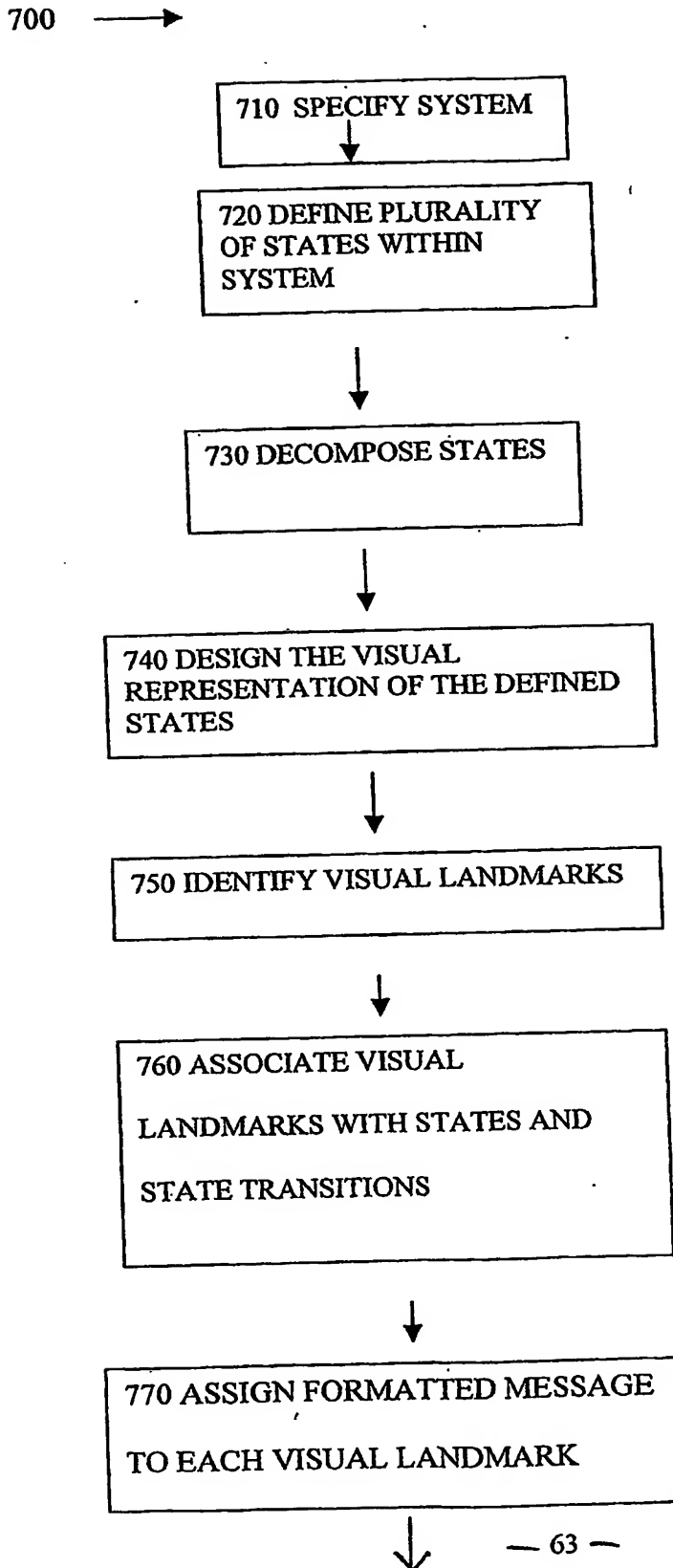
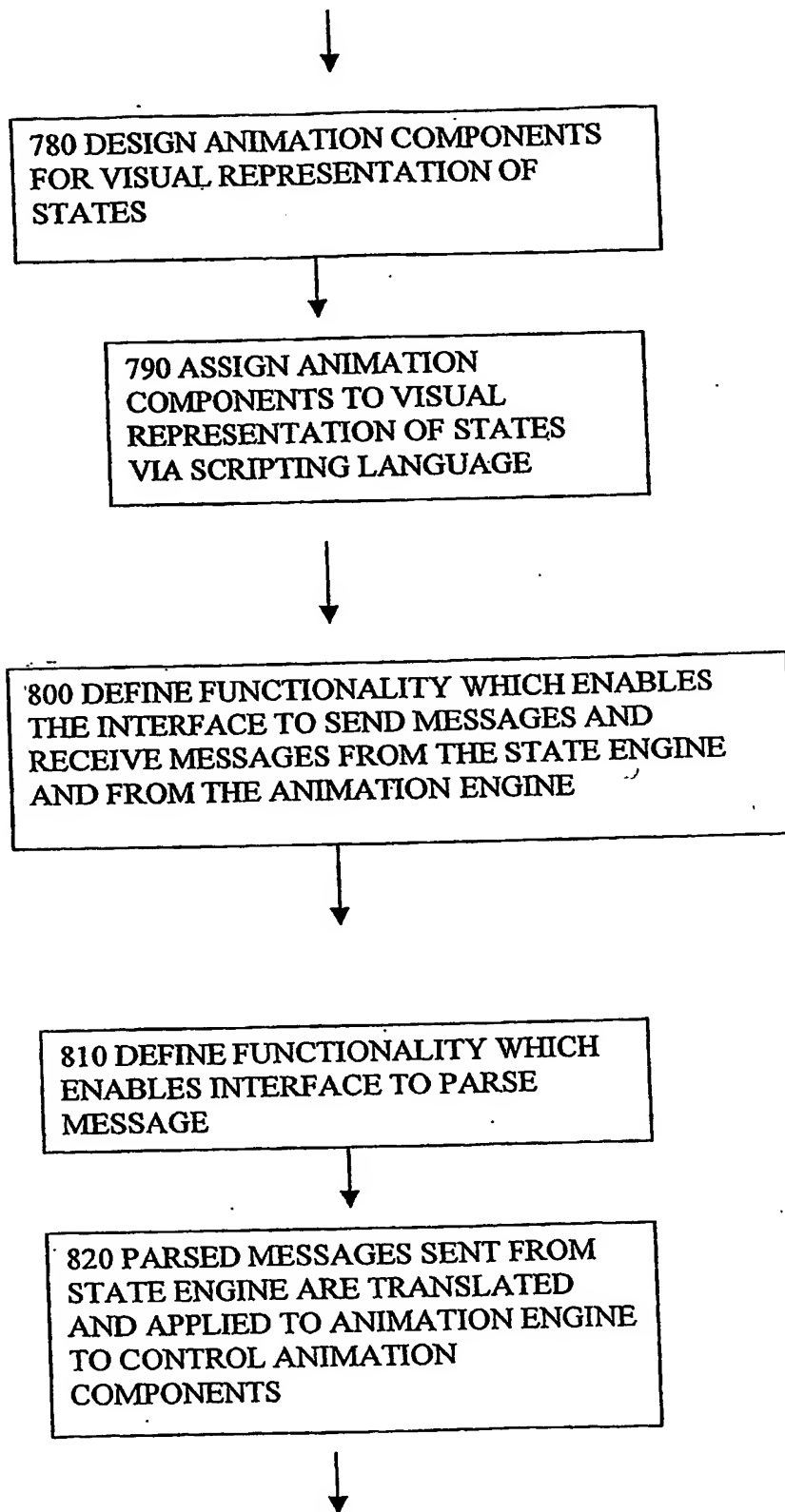


FIG. 4





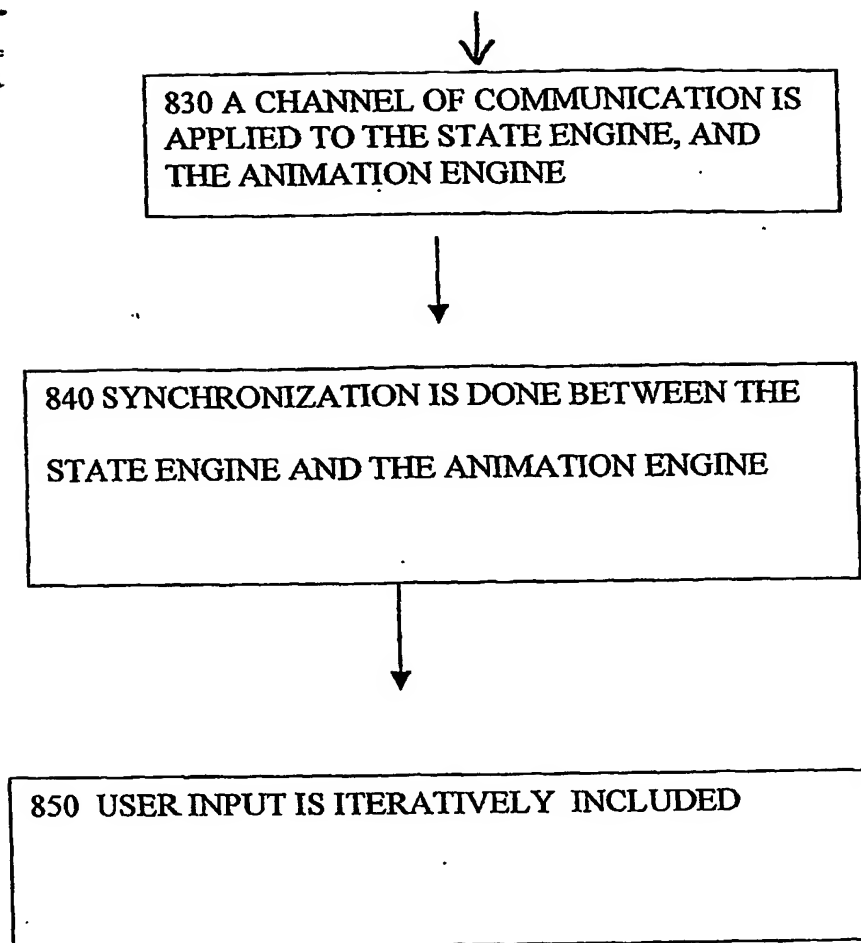


Fig. 4 (Cont.)

FIG. 5

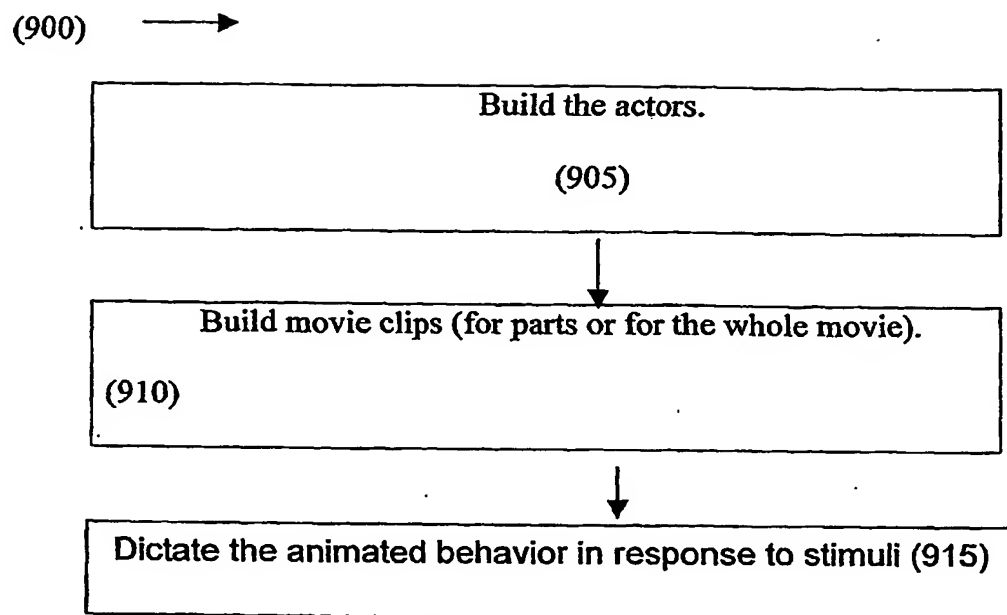


FIG. 6

1000



Describe the behavior of
actors/classes/agents (1010)



Stage the initial conditions (1020)



Specify which of the events that happen
should be sent to the animation engine. (1030)



Specify how the messages are sent. (1040)



Run the movie. (1050)

Figure 7

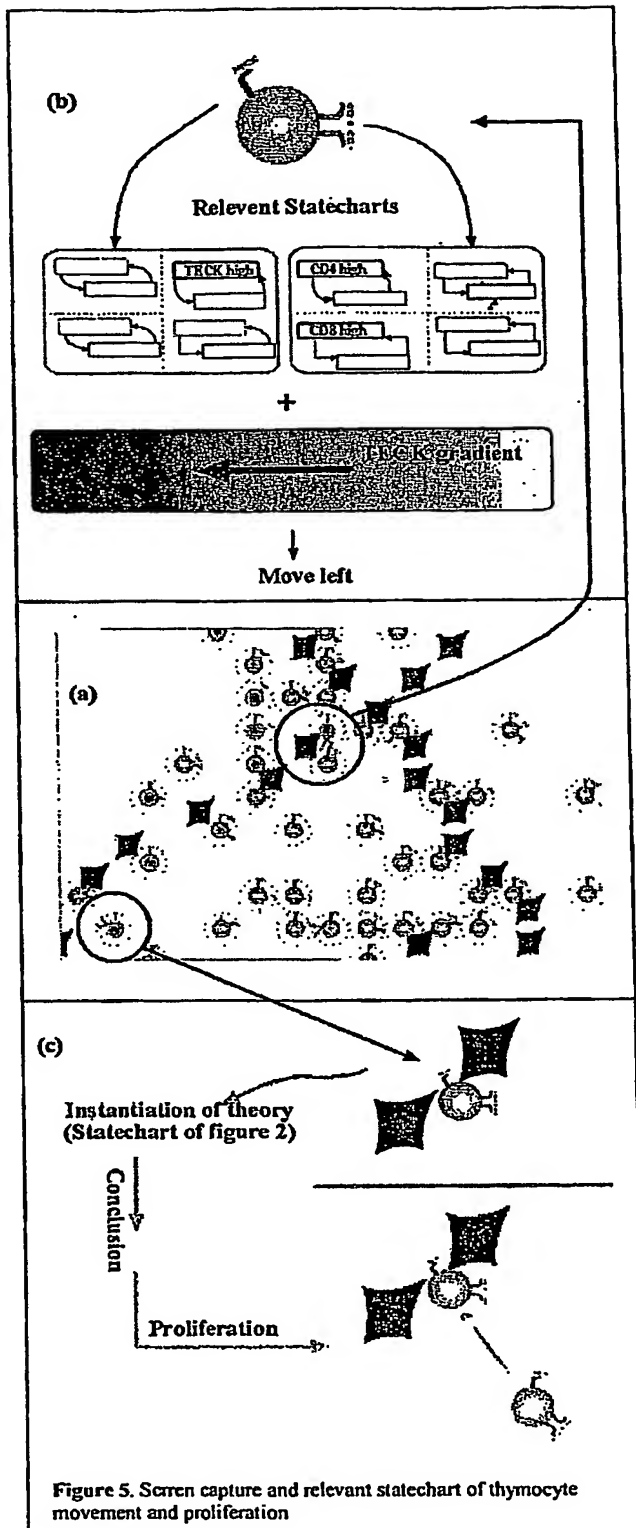


Figure 8

